AFRL-HE-WP-TR-2002-0227

UNITED STATES AIR FORCE RESEARCH LABORATORY

THE IMPACT OF VISOR TRANSMISSIVITY AND REFLECTIVITITY ON PILOT VISUAL ACUITY AND TARGET ACQUISITION RANGE

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August 2001

FINAL REPORT FOR THE PERIOD 1 OCTOBER 2000 TO 31 AUGUST 2001

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NOTICES

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TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-2002-0227

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Instruction 40-402.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

John Reising

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2002	Final Report 1 October 2000 to 31 August 2001

4. TITLE AND SUBTITLE

The Impact of Visor Transmissivity and Reflectivity on Pilot Visual Acuity and Target Detection Range

5. FUNDING NUMBERS

PR: 7184
TA: 11
WU: 20

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory
Human Effectiveness Directorate
Crew System Interface Division
Air Force Materiel Command
Wright-Patterson AFB OH 45433-7022

10. SPONSORING/MONITORING

AFRL-HE-WP-TR-2002-0227

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The purpose of this study was to experimentally determine the impact of varying degrees of visor transmissivity and reflectivity on visual acuity. This study measured pilot's target detection range when wearing six different visor configurations: (a) no visor, (b) USAF tinted visor, (c) the Visually Coupled Acquisition and Targeting System (VCATS) 25% transmissive visor with a 9% reflective coating, (d) the VCATS 25% transmissive uncoated visor, (e) the VCATS 35% transmissive uncoated visor with a 13% reflective coating. The results of this study showed that detection range decreased as transmissivity was decreased while detection range remained unchanged as reflectivity was increased.

14. SUBJECT TERMS	15. NUMBER OF PAGES
helmet-mounted display visor, transmissivity, visual acuity, coatings	84
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

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DISCLAIMER

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ABSTRACT

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Year: 2001

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CHAPTER I

INTRODUCTION

The purpose of this study was to experimentally determine the impact of varying degrees of visor transmissivity and reflectivity on visual acuity. Since the advent of the air-to-air missile, aircraft and missile designers have been searching for methods to improve and expand the weapons engagement zone (WEZ) of the weapons. The WEZ is the region that a fighter aircraft must maneuver into in order to employ weapons against a target aircraft. While the weapons have continually evolved, the mechanisms to aim these missiles have been limited to the aircraft's fire control radar (FCR) and the heads-up-display (HUD). Both systems offer a huge advantage over an adversary that is not similarly equipped; however, in light of the capabilities of the latest generation of high off-boresight weapons, both have significant limitations. Off-boresight is the term used to describe the angular difference between the longitudinal axis of the aircraft and the boresight of the cueing source.

Current Weapons Aiming Mechanisms

Today's highly dynamic air-to-air combat environment demands weapons and cueing systems that are capable of slaving at rates of several hundred degrees per second and at off-boresight angles in excess of 90 degrees. The advent of helmet mounted

cueing systems expanded the WEZ well beyond the FCR and HUD and allows the pilot to employ off-boresight weapons to their full potential.

Fire Control Radar

The FCR was the first system to provide the capability to slave weapons off-boresight. By using the FCR, a pilot can slave both weapons and sensors to the radar's line-of-sight. However, the FCR is not optimized for the dynamic within-visual-range (WVR) arena. The FCR has relatively slow slaving rates, long delays associated with the transition from target acquisition to track and fixed scan patterns that force the pilot to maneuver his aircraft into specific positions in order to obtain a radar track. Additionally, once the radar is in track, current FCRs' off-boresight capabilities are limited to between sixty and seventy degrees, thus limiting the new generation of weapons (McDonnell Douglas Aerospace, 1997).

Heads Up Displays

The introduction of the HUD in the 1950's provided the ability to display dynamic aiming references for both the gun and missiles by projecting symbology onto a combining glass mounted directly in front of the pilot (Figure 1, p. 3). Instead of having to look inside the cockpit to determine aircraft and weapons parameters, the pilot could look outside the cockpit through the HUD and obtain valuable information while still maintaining situational awareness outside the cockpit (Adam, 1995).

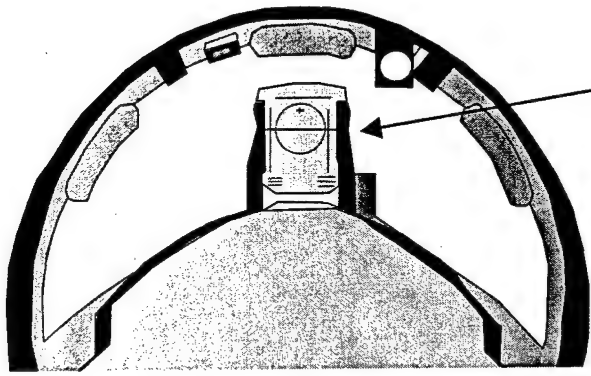


Figure 1. Heads Up Display

Although the HUD is a quantum leap over its predecessors, it still has limitations, primarily because it is fixed to the aircraft. To aim a weapon using the HUD, the pilot must maneuver to bring the target into the HUD's field of view, which is fixed along the aircraft's boresight. The result is the loss of the off-boresight capability of the weapon (Adam, 1995).

Helmet Mounted Systems

One solution to the limitations of the FCR and the HUD was to design a helmet mounted cueing system that allowed the pilot to aim weapons simply by pointing the boresight of the helmet at a target. Today's helmet mounted cueing systems are classified into one of two categories: helmet mounted sight (HMS) and helmet mounted tracker and display (HMT/D). Both systems allow the pilot to aim sensors and weapons, but the HMT/Ds go a step further by displaying the symbology that is on the HUD, plus additional information, on the helmet visor in front of the pilot's eyes (Adam, 1995).

Helmet Mounted Sights

The HMS is the most rudimentary of the helmet mounted cueing systems. The primary purpose of the HMS is to designate targets for a sensor or a weapon. The two major components of a HMS system are an aiming device and a helmet tracker, a means to determine the helmet line-of-sight. The aiming device can be as simple as a crosshair on the helmet visor or a small combining glass positioned in front of the pilot's eye. To use the HMS, the pilot simply puts the aiming device on a target and then commands the sensor or weapon to slave to the helmet line-of-sight and track the target (Adam, 1995).

Helmet Mounted Displays

While an HMS system is useful for aiming high off-boresight weapons, it lacks the flexibility to display information directly in front of the pilot's eyes. An HMT/D adds a graphics display device, usually in the form of a cathode ray tube (CRT), to an HMS to provide this capability. The CRT image is projected onto the helmet visor, which in turn reflects the image back to the pilot, thus providing the pilot with a HUD-like image displayed directly in front of his eyes (Gunther, 1995).

HMT/Ds offer the advantages of a HUD without the limitation of being fixed to the aircraft. Regardless of where the pilot is looking, there is a heads-up display on the visor. High off-boresight weapons can be aimed and proper tracking verified by simply looking at the target. This capability comes at a cost however. For the system to operate the pilot must be wearing a visor, and the visor must possess some degree of reflectivity so that the CRT image can be reflected back into the pilot's eye. The reflectivity of the visor can be inherent to the design of the visor, or can be achieved by applying a

reflective coating to the inner surface of the visor. The combination of the visor and the reflective coating reduce the amount of light that reaches the pilot's eyes and can increase the amount of unwanted reflected light (Kocian, 1999).

Properties of Light

Understanding the properties of light is critical to understanding the complexities of helmet mounted display (HMD) design. The most commonly used material in military visors is plastic, usually polycarbonate. Although plastic has many desirable qualities, it also has several negative optical effects that are not normally associated with glass. These limiting effects include rainbowing, multiple imaging, distortion, and haze (Kocian and Task, 2000).

I - Incident Light
R - Reflected Light
A - Absorbed Light
S - Scattered Light
T - Transmitted Light

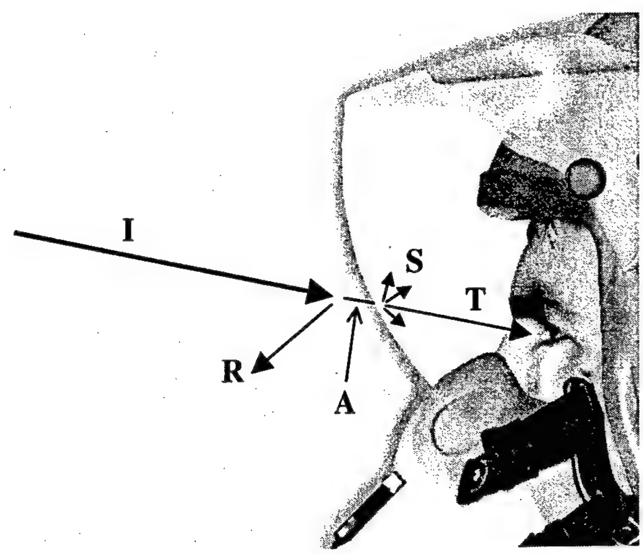


Figure 2. Properties of Light.

Light that is incident on a transparent surface, in this case a visor, can be absorbed, reflected, scattered or transmitted as shown in Figure 2. Only the transmitted

and reflected light maintains image forming potential. The light that passes through the visor consists of both the transmitted light and the scattered light. The result of scattered light passing through the transparency is referred to as a veiling luminance due to haze. The National Bureau of Standards (NBS) defines haze as the ratio of scattered light (S) to the total light (S + T) (see Equation 1) coming through a transparent surface (Task and Genco, 1985).

Equation 1

$$H = \frac{S}{S + T}$$

The result of haze is a reduction in the contrast between a target and the surrounding background. The contrast between a target and the background when not viewed through a transparent surface is defined in Equation 2. The contrast due to haze, when viewing the same target and background through a transparent surface, is defined in Equation 3 (p. 7). The result of haze is a reduced capability to discern targets from the background (Task and Genco, 1985). To a pilot this translates into reduced target visual detection range and a tactical disadvantage.

Equation 2

$$C = \frac{|L_T - L_B|}{L_T + L_B}$$

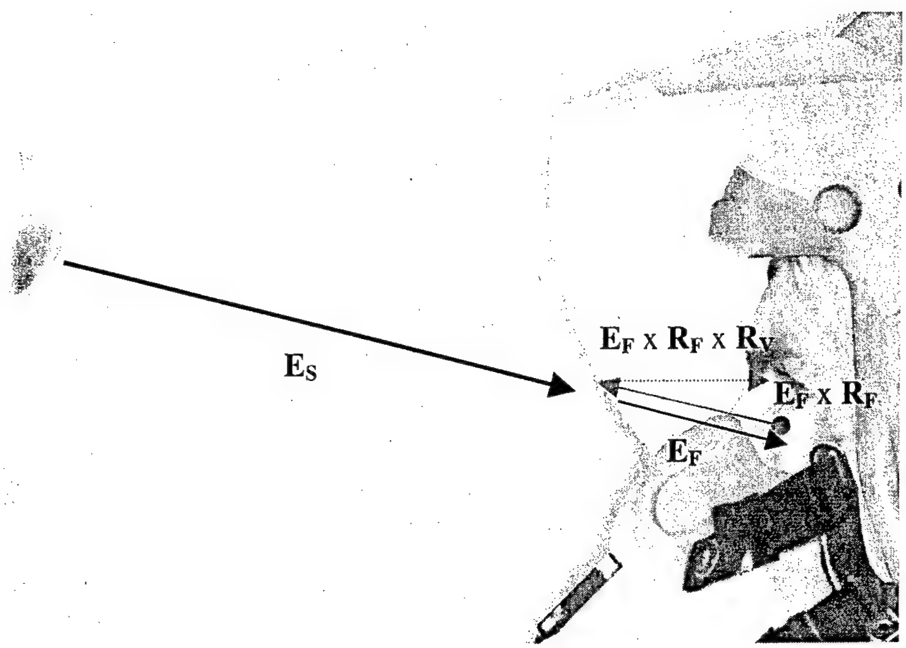
C = Contrast
L_T = Target luminance
L_B = Background luminance

Equation 3

$$C_H = \frac{C}{1 + 2\,\dfrac{L_H}{(L_T + L_B)*T_V}}$$

C_H = Contrast due to haze
L_H = Veiling luminance due to haze
T_V = Visor transmission

The total amount of light reaching the pilot's eyes consists of light from the target of interest, light from the background, scattered light (veiling luminance) and also unwanted reflected light (Figure 3).



E_S = Illuminance at visor from sun
E_F = Illuminance at face from sun
R_F = Face diffuse reflectance coefficient
R_V = Visor reflection coefficient

Figure 3. Extraneous Reflected Light Inside the Visor.

The extraneous reflected light is caused by the reflective properties of the pilot's face and the visor. As light passes through the visor, some of it is reflected off the pilot's face. A portion of this light is subsequently reflected off the inside of the visor and back into the pilot's eyes. This extraneous reflected light has no useful image forming characteristics and further decreases contrast and the ability to discern targets from the background. The image formed by the reflected light can also act as a distraction to the pilot (Kocian and Task, 2000).

Problem Statement

To bridge the gap between the new generation of high off-boresight weapons and their aiming mechanisms, helmet mounted cueing and display systems are becoming standard equipment on modern fighter aircraft. The HMT/D enables the pilot to aim weapons and sensors by simply pointing the helmet boresight at a target while also providing a display capability on the pilot's visor. These systems are still evolving, however, and a major technological hurdle being addressed is the optical design. The problem is to design a system that displays information in front of the pilot's eyes without causing a significant decrease in visual acuity.

The 422 Test and Evaluation Squadron (TES) at NELLIS AFB, NV, has operationally tested several HMT/D configurations since 1993. The subjective data gathered from pilot surveys indicated that the light transmission properties of the visor and the reflective coating had a significant impact on visual acuity and combat effectiveness (Kocian, 1999).

This study conducted a quantitative assessment of the impact of visor transmissivity and visor reflectivity on pilots' visual acuity. Specifically, it was determined that in a static environment increasing visor transmissivity decreased visual target detection range. It was also determined that under the same conditions, increasing visor reflectivity had no significant impact on visual target detection range.

CHAPTER II

REVIEW OF RELEVANT LITERATURE AND RESEARCH

Helmet Mounted Display Mechanization

HMDs are highly complex systems that must display information directly in front of the pilot's eyes while minimizing degradation to the pilot's outside visual acuity. Current U.S. HMD systems gather and process information that is subsequently transformed into visual images and displayed on the pilot's visor through the use of a CRT. The image generated by the CRT is collimated and projected onto the helmet visor, which in turn reflects the image into the pilot's eye as shown in Figure 4 (Jackson, 1998).

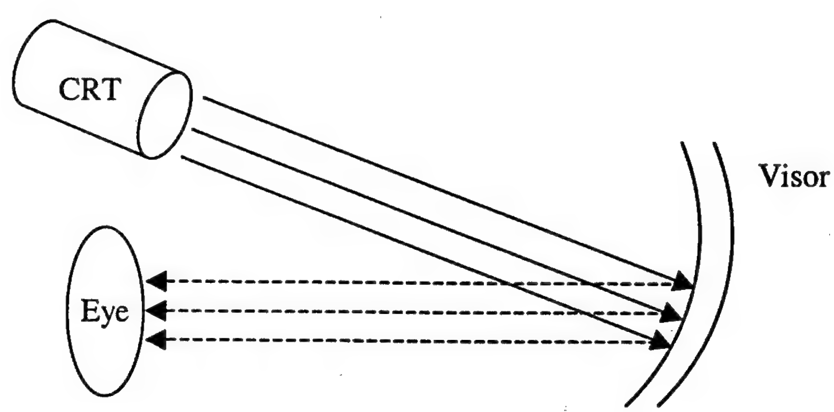


Figure 4. Light From the CRT Is Reflected Off the Visor and Into the Pilot's Eye.

The combination of the image source and the visor is a critical part of the HMD. For the image to be visible to the pilot, a certain level of light must be reflected

off the visor and directed into the eye. Since the visor is not designed to be a perfect reflector, it acts as a transparent surface. As discussed earlier, the light transmitted from the CRT will be absorbed, reflected, scattered and transmitted as shown in Figure 5. The result is a much lower level of light reaching the eye than is transmitted from the CRT (Ryer, 1999).

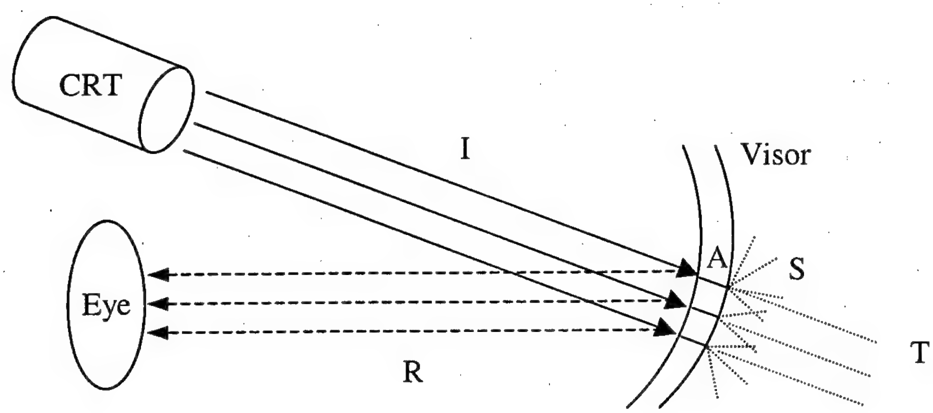


Figure 5. Light Reflection, Absorption, Transmission and Scattering.

Increasing the reflectivity of the visor or increasing the output power of the CRT will increase the amount of light reflected into the pilot's eye. However, each solution comes at a cost. Increasing the reflectivity on the inside of the visor decreases the light transmission from outside the visor and increases the amount of extraneous light from unwanted reflections. The loss of transmissivity can be calculated by using Equation 4 (p. 12) (Kocian and Task, 2000). The end result is reduced visual acuity outside the cockpit.

Equation 4

$$T_{VC} = T^*(100-R_{VC})$$

T_{VC} = Visor transmissivity with reflective coating
T = Visor transmissivity uncoated
R_{VC} = Reflectivity of visor coating

Increasing the CRT output power also creates problems. The requirement for high power can lead to increased size and weight of the CRT and higher failure rates for the components. Additionally, a high-powered CRT with a low reflective visor can create a problem with double imaging, known as ghosting. Figure 6 shows that as light strikes the visor, some will be reflected off the inner surface of the visor and some will be reflected off the outer surface. The result is two images reflected into the pilot's eye, a primary image and a ghosted image (Kocian, 1999).

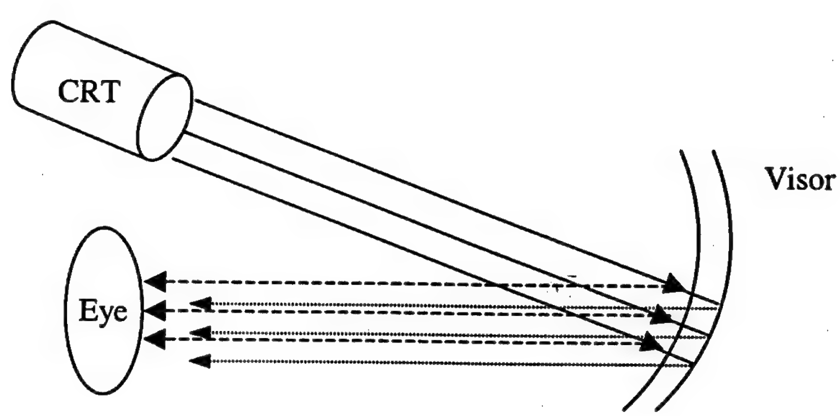


Figure 6. Ghosting.

U.S. Helmet Mounted Display Programs

From August 1986 to July 1992, the Human Engineering Division of Armstrong Laboratory (AL) began a series of simulations designed to quantify USAF HMT/D requirements. The simulation program, named Vista Sabre, demonstrated a 50:1 kill ratio when pilots employed the Kaiser Electronics, Agile Eye HMT/D. Based on these results, the USAF approved an operational flight test, Vista Sabre II, to assess the utility of the Agile Eye HMT/D with a high off-boresight angle (HOBA) missile in an air-to-air engagement (Kocian, 1999).

The Vista Sabre II test was a tremendous success; however, it highlighted several deficiencies of the Agile Eye HMT/D system. The Agile Eye HMT/D was retired in 1996 and replaced by the Visually Coupled Acquisition and Targeting System (VCATS). Armstrong Laboratory, now renamed the Air Force Research Laboratory (AFRL), along with Kaiser Electronics and McDonnell-Douglas Aircraft, built on the lessons learned from Vista Sabre II to produce a more operationally representative HMT/D. VCATS continued to build on the Vista Sabre II lessons and has fed valuable information to the Joint Helmet Mounted Cueing System (JHMCS) which began testing in 1999, and is programmed to become operational in the USAF in 2002 (Kocian, 1999).

Vista Sabre II

Vista Sabre II consisted of modifying two 422 TES F-15Cs to accommodate the Kaiser Electronics Agile Eye, Agile Eye Plus, Agile Mark III and Mark IV HMT/Ds. The

first flight with the Agile Eye was in April 1993 and testing began in October 1995. The Agile Eye was a lightweight, full function, monocular, stroke display HMT/D system. It used a modified USAF HGU-55/P helmet, which displayed data on the visor in front of the pilot's right eye through a fifteen to twenty degree field-of-view. Table 1 outlines the different combinations of visor transmissivity and reflectivity that were tested on the Agile Eye helmets. It should be noted that the transmission levels in Table 1 are the values before the reflective coating was added (D. Kocian, personal communication, May 12, 1999).

Table 1

Vista Sabre II Visor Transmissivity and Reflectivity

	Visor Transmission	Reflective Coating
Agile Eye Mark III	Clear - 100%	30% patch
Agile Eye Mark III	Tinted - 13%	18% patch
Agile Eye Mark IV	Clear - 100%	30% patch
Agile Eye Mark IV	Tinted - 13%	18% patch
Agile Eye Mark IV	Tinted - 25%	18% patch

The patch used on the Agile Eye HMT/D was an oval reflective patch that was deposited onto the visor in front of the pilot's right eye. The purpose of the patch was to provide a reflective surface for the field of view of the HMD without having a reflective

coating added to the entire visor. Unfortunately, it caused a significant visual problem. Because the majority of the visor was uncoated, the pilot's eye adjusted to this brighter light level. When the target was brought into the coated area, it disappeared against the darker background. There was a noticeable time delay before the pilot's eye could readjust and detect the target in the patched area. The result was significantly reduced target acquisition ranges within the display portion of the HMD. The recommendation from the Vista Sabre II final test report was to design an HMD that did not require a patch (Olson, 1996a).

Visually Coupled Acquisition and Targeting System

The primary purpose of the VCATS program was to build a completely redesigned HMT/D, based on the lessons learned from Vista Sabre II, that would serve as a risk reduction model for the USAF's future HMT/D, the JHMCS (Olson, 1996b). The VCATS test began in 1997 and testing continues by the 422 TES at Nellis AFB, NV.

Determining the optimum combination of optical hardware, visor transmissivity and visor reflectivity was a major goal of the VCATS program. The problems with visor reflectivity discovered with the Agile Eye HMT/D led AFRL to pursue a more powerful CRT for VCATS. The result was a "hot tube" design that increased the working voltage of the CRT from the 8 kilovolts used in previous HMD systems to 11.8 kilovolts. The corresponding increase in power allowed more flexibility in the design of the visor, particularly a reduction in the required reflectivity (Kocian, 1995).

The solution to the problems created by the patch was to use a visor that had a reflective coating applied to the entire visor. This approach allowed the pilot's eye to view a uniform area and adjust to just one light level. Table 2 outlines the different combinations of transmissivity and reflectivity used on the VCATS visors (D. Kocian, personal communication, May 12, 1999).

Although the uniform visor solved the problem of the eye needing to adjust to different light conditions, it created a new problem. The coating on the early VCATS visors was so reflective that the pilots could see their own facial features on the visor (Olson, 1996a). Additionally, the reflective coating reduced the visor's initial 25% transmissivity as shown in Table 2.

Table 2

VCATS Visor Transmissivity and Reflectivity

Visor Transmissivity (Before Coating Added)	Reflective Coating	Visor Transmissivity (After Coating Added)
Tinted - 25%	9%	22.5%
Tinted - 25%	6.5%	23.5%
Tinted - 25%	Uncoated (4% reflectivity)	25%
Tinted - 35%	Uncoated (4% reflectivity)	35%

The combination of the reflections and the reduced transmissivity led the pilots to report a significant reduction in their visual acuity, target detection ranges and overall combat effectiveness. To compound the problem, the visor was not interchangeable in flight. In reduced lighting conditions, such as at dusk or when flying under an overcast cloud layer, the dark visor became even more difficult to use (McComas, 1998).

The solution was to use a completely uncoated visor. The uncoated visor provided an inherent 4% reflectivity, which was compatible with the "hot tube" CRT, and maintained the 25% transmissivity level. The follow-on to the 25% uncoated visor was a 35% uncoated visor. With the new uncoated visors, the pilots reported a significant improvement in target detection ranges and overall combat capability (McComas, 1998).

Pilots and Visual Acuity Research

Since pilots began wearing sunglasses and visors in the cockpit, the question of how such devices impact visual acuity has been highly debated. Both the Air Force and the Navy have conducted research into this topic.

Air Force Research

The Air Force Research Lab (AFRL) has conducted several studies to quantitatively determine the impact of HMD visors on visual acuity. In 1985, Dr. Task and Lieutenant Colonel Genco published a study that expanded on the NBS definition of haze (Equation 1, p. 6) and developed a method for estimating the loss of visual acuity due to haze. Haze was defined as the loss of scene contrast encountered when light is

scattered off of a transparent surface. The study demonstrated, both mathematically and experimentally, that as the transmission properties of a transparent surface decreased, there was a corresponding loss of scene contrast (Task and Genco, 1985).

Another AFRL study by Mr. Kocian and Dr. Task was done in February 2000 to determine the effects of reflective coatings applied to a visor on visual acuity. For their study, Mr. Kocian and Dr. Task derived mathematical equations to determine the theoretical contrast for a visor without a reflective coating (Equation 5) and a visor with a reflective coating added (Equation 6).

Equation 5

$$C_U = \frac{C}{1 + 2(E_S * R_F * R_V)/(L_T + L_B)}$$

Equation 6

$$C_C = \frac{C}{1 + 2(E_S * R_F * R_{VC})/(L_T + L_B)}$$

Where:

C = Contrast (equation 2)
C_U = Contrast - uncoated visor
C_C = Contrast - coated visor
L_T = Target luminance
L_B = Background luminance
R_F = Face diffuse reflectance coefficient
R_V = Visor reflection coefficient - no coating
R_{VC} = Visor reflection coefficient with coating
E_S = Illuminance at visor from sun

Using Equations 5 and 6, Mr. Kocian and Dr. Task determined the theoretical contrast of a target against a blue-sky background when viewed without a visor and when

viewed through two typical HMD visor configurations. The first visor was not coated and had an inherent 3.5% reflectivity. The second visor had a 13% reflective coating added. The results are noted in Table 3. The same computations were accomplished for a target against a ground background and the results are shown in Table 4.

Table 3

Target Vs. Blue Sky Contrast Example (Kocian and Task, 2000)

Contrast Condition	**Contrast Value**	**Contrast Loss (%)**	**Contrast Loss (%)**
No Visor	0.33	Baseline	
Uncoated Visor	0.27	18.9	Baseline
Coated Visor	0.19	46.4	33.9
Input Values:			
$L_T = 300$ ft-L	$R_V = 0.035$	$E_S = 10000$ ft-c	
$L_B = 600$ ft-L	$R_{VC} = 0.13$	$R_F = 0.3$	

Table 4

Target Vs. Ground Contrast Example (Kocian and Task, 2000)

Contrast Condition	**Contrast Value**	**Contrast Loss (%)**	**Contrast Loss (%)**
No Visor	0.23	Baseline	
Uncoated Visor	0.18	23.7	Baseline
Coated Visor	0.11	53.6	39.2
Input Values:			
$L_T = 100$ ft-L	$R_V = 0.035$	$E_S = 3850$ ft-c	
$L_B = 160$ ft-L	$R_{VC} = 0.13$	$R_F = 0.3$	

The results in Tables 3 and 4 demonstrated that a change in contrast occurs as the visor reflectivity is increased. It should also be noted that the percentage loss does not match the percentage increase in the reflectivity. Compared to no visor, the uncoated visor caused a contrast loss of 18.9% and 23.7% against a blue sky and ground background respectively. Compared to the same baseline, the coated visor caused a contrast loss of 46.4% and 53.6% (Kocian and Task, 2000).

As significant as these numbers are, the actual loss in visual acuity may be even worse. According to Mr. Kocian and Dr. Task, the analysis gained from using Equations 5 and 6 underestimates the problem. The reason for this is that the reflections off the pilot's face and off the visor are not uniform veiling luminances (an assumption used to simplify Equations 5 and 6). Instead, the reflections are non-uniform and have structure corresponding to the pilot's facial features. As a result the pilot may actually see his own facial features reflected off the visor. These structured reflections may further degrade the pilot's visual acuity by actually masking the target of interest, distracting the pilot, or serving as an accommodative trapping mechanism (Kocian and Task, 2000).

<u>Navy Research</u>

In August of 1991, the U.S. Navy (USN) conducted a study of 126 Navy fighter pilots to assess visor wear habits and the impact of the visor on visual acuity. The visor studied was the USN/USAF standard tinted visor. The transmissivity of the standard visor is 12%. The tinted visor has an inherent reflectivity of approximately 4% (Morris,

Temme, and Hamilton, 1991).

The Navy study revealed that the 126 pilots had significantly different wear habits. Some of the pilots wore their visor all of the time, others wore the visor only during certain portions of the flight and others never wore the visor. Additionally, the study revealed a decrease in visual acuity due to the helmet visor (Morris, Temme, and Hamilton, 1991). A follow-up USN study concluded that when pilots wore the standard 12% neutral filter aviator sunglasses, they suffered a 5% decrease in visual detection range (March, Cushman, and Temme, 1991).

Statement of the Hypothesis

The desire to direct weapons and sensors at high off-boresight angles has generated the requirement for helmet mounted cueing systems. This new capability has come at a cost. In order to display images to the pilot, the system requires the pilot to wear a visor and the visor possesses some degree of reflectivity. The combination of the visor and the reflective coating reduce contrast ratio between the target and the surrounding background. Therefore, this study tested two hypotheses.

1. It was hypothesized that the target detection range of USAF F-15C, F-15E and F-16C pilots would decrease as the transmissivity of the visor was decreased.

2. It was hypothesized that the target detection range of USAF F-15C, F-15E and F-16C pilots would decrease as the reflectivity of the visor was increased.

CHAPTER III

RESEARCH METHODOLOGY

Research Technique

An experimental approach to determine the effect of visor transmissivity and visor reflectivity on target acquisition range under high illumination conditions was employed. Six different visor configurations where used.

Research Design

The experiment population consisted of 12 F-15C, F-15E and F-16C pilots. The study determined if visor transmissivity and visor reflectivity impact visual acuity, measure by visual target detection range. The test design allowed the researcher to control most of the external variables, such as sun angle, lighting conditions, and background-to-target contrast ratio.

Pilots where tested under the same environmental conditions using six different visor configurations: (a) no visor, (b) standard USAF tinted 12% transmissive visor (hereafter referred to as USAF tinted), (c) VCATS uncoated 25% transmissive visor (VCATS 25% uncoated), (d) VCATS 25% transmissive visor with a 9% reflective coating (VCATS 25% coated), (e) VCATS uncoated 35% transmissive visor (VCATS 35%), and (f) the JHMCS 25% transmissive visor with a 13% reflective coating (JHMCS). The different transmissive and reflective properties of each visor

configuration are contained in Table 5. Testing was accomplished during high illumination conditions.

Table 5

Experimental Visor Transmissivity and Reflectivity

	Transmissivity	Reflective Coating	Reflectivity
No Visor	100%	None	0%
USAF Tinted	12%	None	4%
VCATS 25% Uncoated	25%	None	4%
VCATS 25% Coated	22.5%	9%	9%
VCATS 35%	35%	None	4%
JHMCS	21.75%	13%	13%

Note. Transmissivity of coated visors derived using equation 4 (p. 12).

The impact of visor transmissivity on visual acuity was measured by comparing the target detection ranges as the transmissivity was reduced. Detection range was measured without a visor and as transmissivity was incrementally reduced using the VCATS 35% visor, the VCATS 25% uncoated visor and the USAF tinted visor.

The impact of visor reflectivity was measured by comparing the detection ranges between three visors that had similar light transmission properties but varied in their reflective properties: VCATS 25% uncoated visor, VCATS 25% coated visor and the JHMCS visor. Although the transmissivity of the three visors varied slightly after the

coating was added (25%, 22.5% and 21.75% respectively) the major difference was the amount of reflective coating added to the visor.

Population

This study used a convenience population consisting of 12 pilots flying the F-15C, F-15E, and F-16C in the 422 TES at Nellis AFB, NV. Not all of the pilots where qualified to fly with the VCATS or JHMCS systems; however, for this study, being qualified to fly with the HMD was not a requirement and had no impact on the data gathered. All that was required was that the pilots wear a helmet with the six different visor configurations.

The data gathered from the convenience population applies to a target population of all F-15C, F-15E and F-16C pilots in the USAF that fly with any of the six previously described visor configurations or any visor with similar transmissive and reflective properties. The pilots assigned to the 422 TES are a representative sample of all the F-15C, F-15E and F-16C pilots in the USAF. They must pass the same vision tests as the rest of the pilots in the USAF and have visual acuity of 20/20 or better. Their assignment to the 422 TES was in no way dependent on their visual acuity nor was their visual acuity impacted by their assignment to the 422 TES. The 422 TES pilots represent a random sample of the visual acuity of the pilots in the USAF.

Data Gathering Instruments

The test was accomplished by using a Four Alternative Forced-Choice Target Detection Task mounted on a testing board. The board was covered with a blue background, colored to simulate a clear, blue sky. An F-15C silhouette, colored in

aircraft gray to simulate the actual F-15C paint scheme, was placed randomly on the board facing either up, down, left or right (Figure 7). The silhouette was a 500:1 scale representation of the actual aircraft. The testing board was mounted on a wheeled stand. This ensured that the stand remained at a constant 90-degree angle.

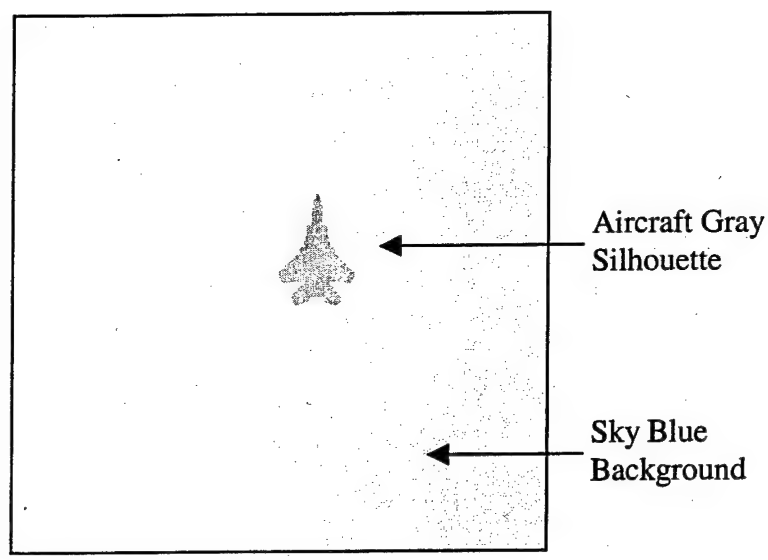


Figure 7. Four Alternative Forced-Choice Target Detection Task Testing Board.

The test consisted of thirty runs, five with each of the six different visor configurations. Between each test run, the aircraft silhouette direction was randomly changed to ensure that the pilot actually detected the target. The order that the visor configurations where tested was randomly determined for each pilot using a random number generator created on Microsoft Excel. The test area was configured as shown in Figure 8 (p. 26). The entire area was measured and marked off in one-foot increments to provide a mechanism for measuring the detection ranges.

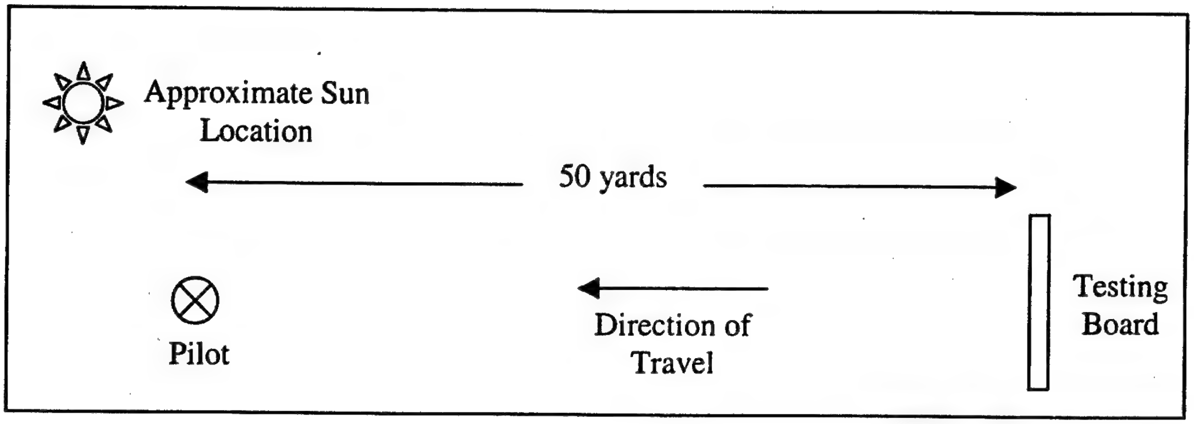


Figure 8. Test Setup Depiction.

The test began with the pilot standing at the zero foot line wearing one of the visor configurations. The testing board was displayed 50 yards from the point where the pilot was standing and beyond the pilot's ability to visually detect the target. The board began moving toward the pilot at a constant rate of approximately three feet per second. Using a 500:1 scale, this rate of closure closely simulated the rate of closure experienced during a typical air-to-air engagement. At the range where the pilot detected the target and determined the target's direction, he declared a tally and stated which direction. If he was correct the range was noted and the run was over. If he was incorrect, the board continued to move closer until a proper direction was declared. The pilot accomplished five runs for each of the six visor configurations.

Each set of test runs was conducted under approximately the same environmental conditions. All testing was accomplished on a clear day with the sun slightly behind the pilot to minimize glare and to minimize the affect of shadows on the target board. Data

was gathered with the sun high in the sky from approximately ten o'clock in the morning until two o'clock in the afternoon.

To ensure consistent lighting conditions, a photometer was used to measure the light conditions between each run. Measurements included the brightness of the target and the brightness of the background, which was used to determine the scene contrast. The overall lighting conditions where also measured by taking a reading of the reflected light off a white, barium plate. This ensured that all runs where conducted under similar contrast and light conditions.

The data gathered from each pilot was entered into a Microsoft Excel spreadsheet for analysis.

Treatment of Data and Procedures

The data gathered during this study consisted of the ranges, measured in feet, at which the pilot detected the target. The data gathered represented a ratio scale of measurement.

To determine the affect of visor transmissivity on visual acuity, the following statistical hypothesis was tested: There is no difference in the visual target detection ranges among the same USAF F-15C, F-15E and F-16C pilots wearing no visor, the VCATS 35% visor, the VCATS 25% uncoated visor, and the USAF tinted visor.

To determine the affect of visor reflectivity on visual acuity, the following statistical hypothesis was tested: There is no difference in the visual target detection ranges among the same USAF F-15C, F-15E and F-16C pilots wearing the VCATS 25% uncoated visor, the VCATS 25% coated visor, and the JHMCS visor.

The data was gathered using the worksheet in Appendix C and entered into a Microsoft Excel spreadsheet. The data for each pilot was divided into six groups corresponding to the six visor configurations.

To determine if there was a significant difference in the mean target detection ranges as visor transmissivity was reduced, a series of T-tests was run on the data from the no visor, VCATS 35% visor, VCATS 25% uncoated visor and the USAF tinted visor runs. An α value of 0.05 was used.

To determine if there was a significant difference in the mean target detection ranges as the visor reflectivity was increased, a series of T-tests was run on the data from the VCATS 25% uncoated visor, VCATS 25% coated visor and the JHMCS visor. An α value of 0.05 was used.

Validity

The purpose of the study was to measure the effect of visor transmissivity and visor reflectivity on target acquisition range. To ensure that this was accurately measured, the researcher controlled the external variables to the maximum extent. The pilots used in the study where all trained on target detection and identification techniques and all possessed visual acuity of 20/20 or better. All of the pilots where qualified operational test pilots.

Each pilot was thoroughly briefed on the specifics of the Four Alternative Forced-Choice Target Detection Task prior to the experiment. To ensure accurate results, the direction of the aircraft silhouette was randomly changed between each run. The sun was behind the pilot so that glare did not adversely impact the ability to see the testing board.

To ensure that the haze index for each visor was constant, only new visors where used for this study and the researcher carefully monitored quality control.

Reliability

To ensure consistent results, all data was gathered under the same environmental conditions. For each of the six different visor configurations the pilot accomplished five data runs to ensure consistency. The researcher supplied the visors for the experiment and the visors where inspected regularly. The researcher and two assistants from the AVTECH Research Corporation conducted all testing. The assistants where trained to operate the testing board. The use of only two assistants minimized variation in testing procedures.

CHAPTER IV

RESULTS

Data Collection

The experiment was conducted at Nellis AFB, NV from November 2000 to January 2001. A population of 12 F-15C, F-15E and F-16C pilots accomplished 5 runs with six different visor configurations for a total of 30 runs for each pilot. The average detection ranges for each pilot are listed in Table 6. The individual pilot test results are listed in Appendix D. The mean target detection ranges for each visor configuration are shown in Figure 9 (p. 31).

Table 6

Individual Pilot Average Target Detection Range (feet)

Pilot	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	84.0	63.4	67.0	76.0	80.2	59.8
2	96.2	88.2	84.2	81.4	92.2	86.0
3	90.2	56.6	59.4	63.4	67.6	61.2
4	80.8	69.2	69.2	69.4	81.4	70.8
5	90.2	56.6	59.4	63.4	63.4	61.2
6	93.6	87.6	64.6	71.6	76.2	63.4
7	85.2	90.2	74.4	87.0	92.0	94.8
8	81.2	86.4	88.4	81.4	90.4	84.2
9	100.4	67.6	90.4	77.8	74.0	86.0
10	83.4	78.6	89.4	96.0	92.8	73.6
11	81.0	61.2	61.2	63.8	67.4	61.4
12	77.2	60.2	54.5	55.0	63.2	53.2
Avg.	**87.0**	**72.2**	**71.9**	**73.9**	**78.4**	**71.3**

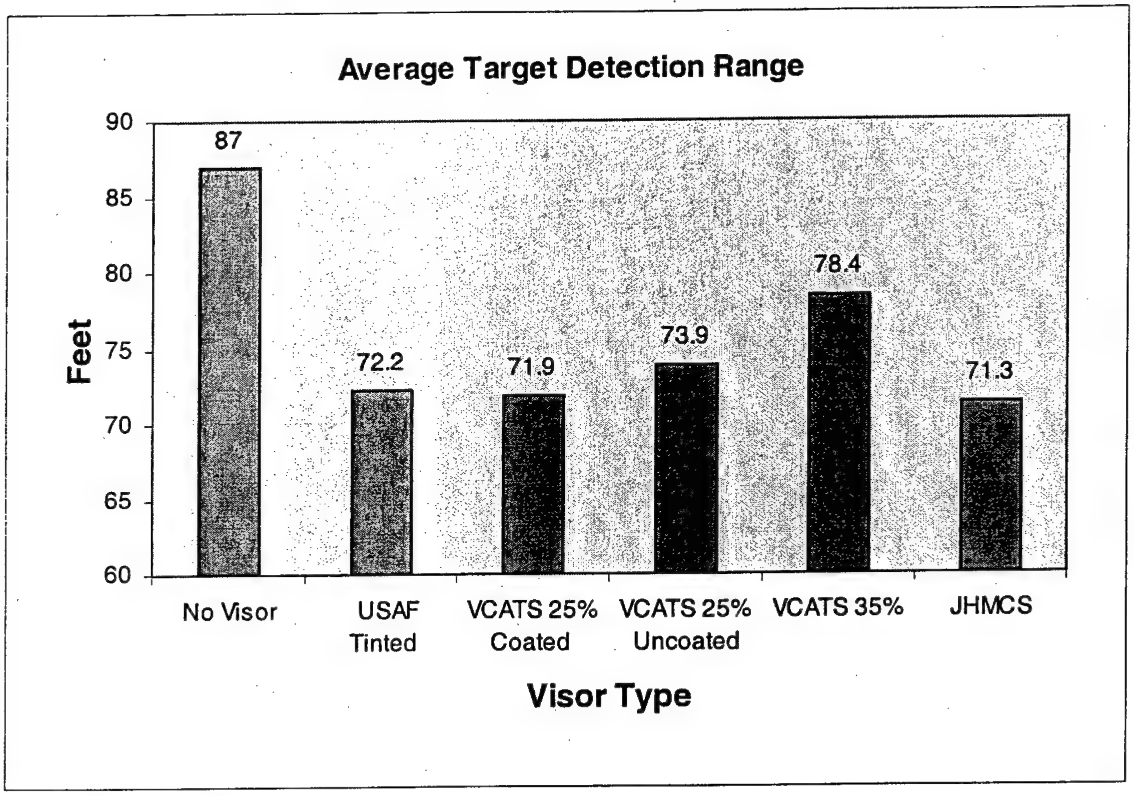


Figure 9. Average Target Detection Range.

The data was gathered under a clear sky and bright sun conditions. A photometer was used to measure the total light at the beginning and end of each pilot's runs. The mean background luminance, L_B, was 496 ft-Lamberts (L) and the mean target luminance, L_T, was 420.5 ft-L. Using Equation 2 the mean scene contrast was calculated at 0.082. The mean of the overall lighting conditions was 920.6 ft-L. The variance in overall lighting conditions was less than six percent for ten of the pilots. The remaining two pilots had less than 10% variance.

Table 7 (p. 32) lists the percentage change in detection range for all pairings of visor configurations. The numbers highlighted in bold indicate a statistically significant

change. Significance was determined using a T-test with an α value of 0.05. Specific T-test results are contained in Appendix E.

Table 7

Percentage Change in Target Detection Range

From \ To	VCATS 35%	VCATS 25% Uncoated	VCATS 25% Coated	JHMCS	USAF Tinted
No Visor	**-9.79**	**-15.07**	**-17.37**	**-18.00**	**-17.02**
VCATS 35%		**-5.84**	**-8.39**	**-9.09**	**-8.01**
VCATS 25% Uncoated			-2.71	-3.45	-2.30
VCATS 25% Coated				-0.77	0.42
JHMCS					1.19

Note. Bold face values indicate a statistically significant change (α = 0.05)

Visor Transmissivity

The first hypothesis tested was that a decrease in visor transmissivity would result in a decrease in visual acuity and a corresponding decrease in target detection range. Four visor configurations were chosen to test this hypothesis: No visor, USAF tinted visor, VCATS 25% uncoated visor, and the VCATS 35% visor. The percentage change for each of the four visor configurations that were tested is listed in Table 8 (p. 33).

To determine if the changes in the mean target detection ranges were statistically significant, a series of T-tests was run on all six possible pairings. Using an α value of 0.05 and 11 degrees of freedom, the critical value for t (t_{crit}) was 2.201. A value of t larger than 2.201 suggested a statistically significant difference between the means of the detection ranges for the two visor configurations being tested. A value of t less than 2.201 was insufficient to reject the null hypothesis, indicating that there was no statistically significant difference between the two visor configurations being tested.

Table 8

Visor Transmissivity Test: Percentage Change in Mean Target Detection Range

To / **From**	**VCATS 35%**	**VCATS 25% Uncoated**	**AF Tinted**
No Visor	**-9.79**	**-15.07**	**-17.02**
VCATS 35%		**-5.84**	**-8.01**
VCATS 25% Uncoated			-2.30

Note. Bold face values indicate a statistically significant change ($\alpha = 0.05$)

The t-value results for the series of T-tests for the four visor configurations tested are listed in Tables 9 (p. 34). The results for each specific T-test are contained in Appendix E. In every case except one, the t-value exceeded t_{crit} indicating that the changes in mean target detection range between the four visor configurations in these five

comparisons were statistically significant. The only test that did not demonstrate a statistically significant change was the comparison between the USAF tinted visor and the VCATS 25% uncoated visor.

Table 9

Visor Transmissivity Test: T-Test Results (*t* Values)

From \ To	VCATS 35%	VCATS 25% Uncoated	USAF Tinted
No Visor	**2.25**	**3.25**	**3.75**
VCATS 35%		**5.00**	**3.00**
VCATS 25% Uncoated			0.67

Note: Bold face values indicate t-value exceeds $t_{crit} = 2.201$

Visor Reflectivity

The second hypothesis tested was that an increase in visor reflectivity would result in a decrease in visual acuity and a corresponding decrease in target detection range. Three visor configurations were chosen to test this hypothesis: VCATS 25% uncoated visor, VCATS 25% coated visor and the JHMCS visor. The percentage change for each of the three visor configurations that were tested is listed in Table 10 (p. 35).

To determine if the changes in the mean target detection ranges were statistically significant, a series of T-tests was run on all three possible pairings. Using an α value of

0.05 and 11 degrees of freedom, the critical value for t (t_{crit}) was 2.201. A value of t larger than 2.201 suggested a statistically significant difference between the means of the detection ranges for the two visor configurations being tested. A value of t less than 2.201 was insufficient to reject the null hypothesis, indicating that there was no statistically significant difference between the two visor configurations being tested.

Table 10

Visor Reflectivity Test: Percentage Change in Mean Target Detection Range

To / From	VCATS 25% Coated	JHMCS
VCATS 25% Uncoated	-2.71	-3.45
VCATS 25% Coated		-0.77

Table 11

Visor Reflectivity Test: T-Test Results (t Values)

To / From	VCATS 25% Coated	JHMCS
VCATS 25% Uncoated	1.00	1.00
VCATS 25% Coated		0.50

The results for the series of T-tests for the three visor configurations tested are listed in Tables 11 (p. 35). The results for each specific T-test are contained in Appendix E. In all three cases the *t*-value did not exceed t_{crit} indicating that the changes in mean target detection range between the three visor configurations were not statistically significant.

CHAPTER V

DISCUSSION

Important Considerations

Before entering into a discussion of the results it is important to understand the impetus and limitations of this experiment. This experiment was developed as a means to quantitatively validate the subjective data gathered from pilots during the Vista Sabre II and VCATS helmet mounted display flight tests. Unfortunately, due to limited resources this experiment was limited to ground testing and the results could not be validated with in-flight testing.

Additionally, in order to limit the number of variables, the experiment was conducted under tightly controlled, static environmental lighting conditions. The highly dynamic lighting conditions experienced during an actual air-to-air engagement will surely introduce variables that will impact (both positively and negatively) the pilot's visual acuity and the ability to visually detect targets.

Visor Transmissivity

This experiment hypothesized that a decrease in visor transmissivity would result in a decrease in pilot visual acuity and a resulting decrease in target detection range. To validate this hypothesis the following statistical hypothesis must be rejected: There is no difference in the visual target detection ranges among the same USAF F-15C, F-15E, and

F-16C pilots wearing no visor, the VCATS 35% visor, the VCATS 25% uncoated visor, and the USAF tinted visor.

The four visor configurations used for this portion of the experiment had different light transmission properties. The visor configurations are ranked from the best case (maximum light transmission) to the worst case (minimum light transmission) according to the following order: No visor, VCATS 35% visor, VCATS 25% uncoated visor, USAF tinted visor. The light transmission properties and target detection ranges for each visor configuration are listed in Table 12.

Table 12

Visor Transmissivity with Corresponding Target Detection Range

	Transmissivity	Target Detection Range (ft)
No Visor	100%	87.0
VCATS 35%	35%	78.4
VCATS 25% Uncoated	25%	73.9
USAF Tinted	12%	72.2

The use of four different visor configurations created six possible transmissivity comparisons. The statistical hypothesis was applied to each comparison individually to determine if there was a significant difference in target detection range. The six comparisons are:

1. No visor to VCATS 35% visor
2. No visor to VCATS 25% uncoated visor
3. No visor to USAF tinted visor
4. VCATS 35% visor to VCATS 25% uncoated visor
5. VCATS 35% visor to USAF tinted visor
6. VCATS 25% uncoated visor to USAF tinted visor

Transmissivity Comparisons

No Visor to VCATS 35% Visor

The mean target detection range for the no visor configuration was 87 feet while the mean target detection range for the VCATS 35% visor was 78.4 feet. Switching to the VCATS 35% visor caused a 9.79% reduction in target detection range. A T-test provided a t-value of 2.25. Using a value for α of 0.05 the corresponding t_{crit} value was 2.201. Since the t-value exceeded t_{crit} the null hypothesis for this comparison could be rejected. There is a significant difference in the visual target detection ranges among the same USAF F-15C, F-15E, and F-16C pilots wearing no visor and the VCATS 35% visor.

No Visor to VCATS 25% Uncoated Visor

The mean target detection range for the no visor configuration was 87 feet while the mean target detection range for the VCATS 25% uncoated visor was 73.9 feet. Switching to the VCATS 25% uncoated visor caused a 15.07% reduction in target detection range. A T-test provided a t-value of 3.25. Using a value for α of 0.05 the

corresponding t_{crit} value was 2.201. Since the t-value exceeded t_{crit} the null hypothesis for this comparison could be rejected. There is a significant difference in the visual target detection ranges among the same USAF F-15C, F-15E, and F-16C pilots wearing no visor and the VCATS 25% uncoated visor.

No Visor to USAF Tinted Visor

The mean target detection range for the no visor configuration was 87 feet while the mean target detection range for the USAF tinted visor was 72.2 feet. Switching to the USAF tinted visor caused an 18% reduction in target detection range. A T-test provided a t-value of 3.75. Using a value for α of 0.05 the corresponding t_{crit} value was 2.201. Since the t-value exceeded t_{crit} the null hypothesis for this comparison could be rejected. There is a significant difference in the visual target detection ranges among the same USAF F-15C, F-15E, and F-16C pilots wearing no visor and the USAF tinted visor.

VCATS 35% Visor to VCATS 25% Uncoated Visor

The mean target detection range for the VCATS 35% visor configuration was 78.4 feet while the mean target detection range for the VCATS 25% uncoated visor was 73.9 feet. Switching to the VCATS 25% uncoated visor caused a 5.84% reduction in target detection range. A T-test provided a t-value of 5.00. Using a value for α of 0.05 the corresponding t_{crit} value was 2.201. Since the t-value exceeded t_{crit} the null hypothesis for this comparison could be rejected. There is a significant difference in the visual target detection ranges among the same USAF F-15C, F-15E, and F-16C pilots wearing the VCATS 35% visor and the VCATS 25% uncoated visor.

VCATS 35% Visor to USAF Tinted Visor

The mean target detection range for the VCATS 35% visor configuration was 78.4 feet while the mean target detection range for the USAF tinted visor was 72.2 feet. Switching to the USAF tinted visor caused an 8.01% reduction in target detection range. A T-test provided a t-value of 3.00. Using a value for α of 0.05 the corresponding t_{crit} value was 2.201. Since the t-value exceeded t_{crit} the null hypothesis for this comparison could be rejected. There is a significant difference in the visual target detection ranges among the same USAF F-15C, F-15E, and F-16C pilots wearing the VCATS 35% visor and the USAF tinted visor.

VCATS 25% Uncoated Visor to USAF Tinted Visor

The mean target detection range for the VCATS 25% uncoated visor configuration was 73.9 feet while the mean target detection range for the USAF tinted visor was 72.2 feet. Switching to the USAF tinted visor caused a 2.3% reduction in target detection range. A T-test provided a t-value of 0.67. Using a value for α of 0.05 the corresponding t_{crit} value was 2.201. Since the t-value did not exceed t_{crit} the null hypothesis for this comparison could not be rejected. There is no significant difference in the visual target detection ranges among the same USAF F-15C, F-15E, and F-16C pilots wearing the VCATS 25% uncoated visor and the USAF tinted visor.

Transmissivity Summary

All six visor transmissivity comparisons demonstrated a reduction in target detection range as visor transmissivity was reduced (Figure 10, p. 42). Five of the six

comparisons demonstrated a statistically significant reduction. It is interesting to note that the one comparison that did not show a significant decrease was the comparison between the two worst case visors, the VCATS 25% uncoated visor and the USAF 12% tinted visor. One possible explanation is that the experiment sample size was not large enough to determine statistical significance in this case.

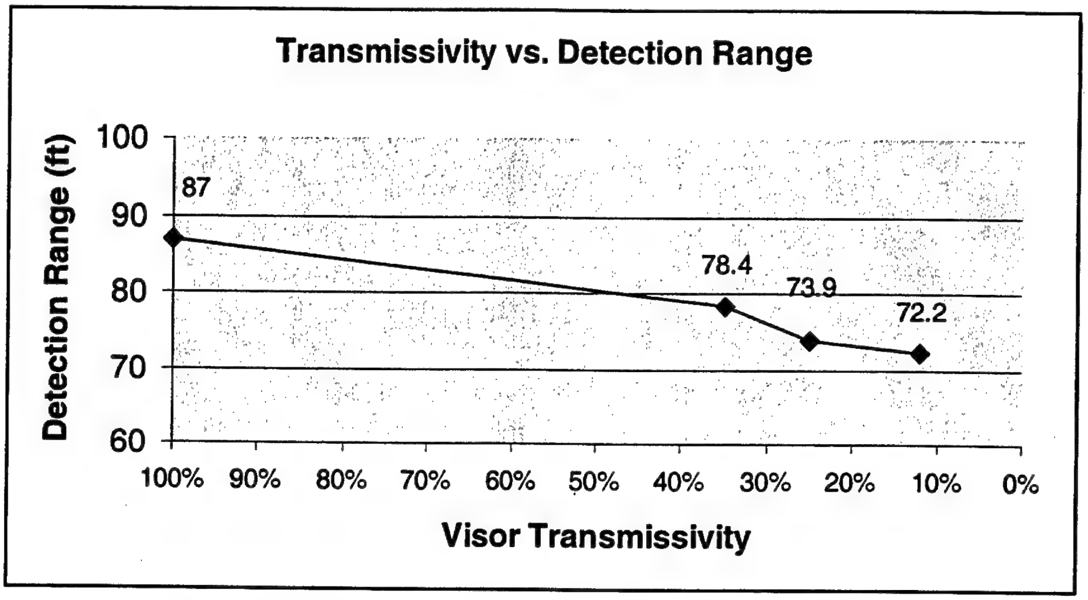


Figure 10. Visor Transmissivity vs. Target Detection Range.

Another possible explanation is that the impact of visor transmissivity on target detection range is reduced as the transmissivity reaches a certain point. In other words, once the visor light transmission properties reach a cut-off point the continued reduction in transmissivity does not have a significant impact on target detection range. Further research is required to investigate this possibility.

Based on the data analysis, the results of this experiment support the following statements:

1. There was a significant decrease in target detection range among the same USAF F-15C, F-15E and F-16C pilots when visor transmissivity was reduced from 100% to 35% or less.

2. There was a significant decrease in target detection range among the same USAF F-15C, F-15E and F-16C pilots when visor transmissivity was reduced from 35% to 25% or less.

With the exception of the comparison between the VCATS 25% uncoated visor and the USAF tinted visor, the data analysis for this experiment supports the research hypothesis that the target detection range of USAF F-15C, F-15E and F-16C pilots would decrease as the transmissivity of the visor was decreased.

The findings of this experiment are consistent with the Vista Sabre II and VCATS flight tests and the 1985 Air Force Research Lab (AFRL) studies described in Chapter II. The loss of scene contrast caused by the decrease in light transmission through a visor caused a decrease in target detection range.

Visor Reflectivity

This experiment hypothesized that an increase in visor reflectivity would result in a decrease in pilot visual acuity and a resulting decrease in target detection range. To validate this hypothesis the following statistical hypothesis must be rejected: There is no difference in the visual target detection ranges among the same USAF F-15C, F-15E, and

F-16C pilots wearing the VCATS 25% uncoated visor, the VCATS 25% coated visor, and the JHMCS visor.

The three visor configurations used for this portion of the experiment had different light reflection properties. The visor configurations are ranked from the best case (minimum reflectivity) to the worst case (maximum reflectivity) according to the following order: VCATS 25% uncoated visor, VCATS 25% coated visor, and JHMCS visor. The reflective properties and target detection ranges for each visor configuration are listed in Table 13.

Table 13

Visor Reflectivity with Corresponding Target Detection Range

	Reflective Coating	Reflectivity	Target Detection Range (ft)
VCATS 25% Uncoated	None	4%	73.9
VCATS 25% Coated	9%	9%	71.9
JHMCS	13%	13%	71.3

The use of three different visor configurations created three possible comparisons. The statistical hypothesis was applied to each comparison individually to determine if there was a significant difference in target detection range. The three comparisons are:

1. VCATS 25% uncoated visor to VCATS 25% coated visor
2. VCATS 25% uncoated visor to JHMCS visor
3. VCATS 25% coated visor to JHMCS visor

Reflectivity Comparisons

VCATS 25% Uncoated Visor to VCATS 25% Coated Visor

The mean target detection range for the VCATS 25% uncoated visor configuration was 73.9 feet while the mean target detection range for the VCATS 25% coated visor was 71.9 feet. Switching to the VCATS 25% coated visor caused a 2.71% reduction in target detection range. A T-test provided a t-value of 1.00. Using a value for α of 0.05 the corresponding t_{crit} value was 2.201. Since the t-value did not exceed t_{crit} the null hypothesis for this comparison could not be rejected. There is no significant difference in the visual target detection ranges among the same USAF F-15C, F-15E, and F-16C pilots wearing the VCATS 25% uncoated visor and the VCATS 25% coated visor.

VCATS 25% Uncoated Visor to JHMCS Visor

The mean target detection range for the VCATS 25% uncoated visor configuration was 73.9 feet while the mean target detection range for the JHMCS visor was 71.3 feet. Switching to the JHMCS visor caused a 3.45% reduction in target detection range. A T-test provided a t-value of 1.00. Using a value for α of 0.05 the corresponding t_{crit} value was 2.201. Since the t-value did not exceed t_{crit} the null hypothesis for this comparison could not be rejected. There is no significant difference in the visual target detection ranges among the same USAF F-15C, F-15E, and F-16C pilots wearing the VCATS 25% uncoated visor and the JHMCS visor.

VCATS 25% Coated Visor to JHMCS Visor

The mean target detection range for the VCATS 25% coated visor configuration was 71.9 feet while the mean target detection range for the JHMCS visor was 71.3 feet. Switching to the JHMCS visor caused a 0.77% reduction in target detection range. A T-test provided a *t*-value of 0.50. Using a value for α of 0.05 the corresponding t_{crit} value was 2.201. Since the *t*-value did not exceed t_{crit} the null hypothesis for this comparison could not be rejected. There is no significant difference in the visual target detection ranges among the same USAF F-15C, F-15E, and F-16C pilots wearing the VCATS 25% coated visor and the JHMCS visor.

Reflectivity Summary

All three visor reflectivity comparisons demonstrated no significant reduction in target detection range as visor reflectivity was increased. This does not support the research hypothesis that the target detection range of USAF F-15C, F-15E and F-16 pilots would decrease as the reflectivity of the visor was increased.

These results were not in line with the test results from the Vista Sabre II and VCATS flight-tests or with the 2000 AFRL study conducted by Dr. Task and Mr. Kocian. Personal HMD experience along with post experiment interviews with Mr. Kocian and several experienced HMD pilots that participated in the experiment offer possible explanations for why the results are inconsistent. The most likely explanation is the differing environments in which the data was gathered.

This experiment was conducted under static environmental conditions to minimize the number of variables. The sun was in a fixed position behind the pilot and shadows were intentionally minimized. The target board was moved toward the pilot so that he was not required to move his head during the data runs. The intent of these restrictions was to minimize variation between pilots and provide the highest level of test validity and reliability.

The result of the strict environment control was that the experiment did not replicate the highly dynamic lighting conditions present during an actual air-to-air engagement. Instead of having to deal with the constantly changing reflections on the visor, the pilots in this experiment stated that they could easily focus beyond the reflections at the target board and tune out the distraction caused by the reflections. Under more dynamic lighting conditions, the constantly changing reflections have the ability to mask the target of interest, distract the pilot, or serve as an accommodative trapping mechanism. All of these conditions could potentially impact target detection range.

The decision to put the sun behind the pilot also minimized the impact of visor reflectivity. Dr. Task and Mr. Kocian's 2000 AFRL study calculated the impact of visor reflectivity on scene contrast. A significant difference between their study and this experiment was the angle of the sun.

The AFRL study placed the sun in front of the pilot, which allowed direct sunlight through the visor. This caused the sunlight to reflect off the pilot's face and onto the

visor. This reflected light would then be reflected off the visor and back into the pilot's eye as shown in Figure 3 (p. 7). The decision to place the sun behind the pilot in this experiment created consistent lighting conditions but largely negated the impact of reflected light off the pilot's face and subsequently off the visor, thus minimizing the role of visor reflectivity.

The impact of sun angle on reflections is supported by pilot debrief comments. A major complaint made by the pilots during the Vista Sabre II and VCATS flight-tests was that they could see their own facial features when flying with a highly reflective visor. Although the same visors were used during this experiment, none of the pilots mentioned any problems with facial feature reflections.

Another difference between this experiment and the flight-testing was the lack of a CRT image. During flight-testing the pilots were forced to contend with the additional distraction of a HMD image on the visor. This condition could not be accurately replicated during ground testing and thus introduced more variables, so the decision was made to leave the CRT turned off for this experiment.

CHAPTER VI

CONCLUSIONS

The purpose of this study was to experimentally determine the impact of visor transmissivity and reflectivity on pilot visual acuity, measured by target detection range. Flight-testing at Nellis AFB, NV suggested that decreasing visor transmissivity and increasing visor reflectivity negatively impacted target detection ranges. These flight-test results are backed up by Air Force Research Lab studies.

Visor Transmissivity

To a certain point the data analysis conducted during this experiment supported the research hypothesis that a reduction in visor transmissivity would cause a reduction in target detection range. Specifically the research supports the following statements:

1. There was a significant decrease in target detection range among the same USAF F-15C, F-15E and F-16C pilots when visor transmissivity was reduced from 100% to 35% or less.

2. There was a significant decrease in target detection range among the same USAF F-15C, F-15E and F-16C pilots when visor transmissivity was reduced from 35% to 25% or less.

Reducing transmissivity from 100% to 35% or less resulted in a decrease in target detection range. The best case comparison (no visor to VCATS 35% visor) resulted in a

9.79% reduction while the worst case comparison (no visor to the USAF tinted visor) resulted in over a 17% reduction in target detection range.

Further reduction of transmissivity from a baseline of 35% also caused a reduction in target detection range. Reducing light transmission from 35% to 25% resulted in a 5.84% reduction in detection range. Reducing transmissivity from 35% to 12% decreased detection range by 8.01%.

These results are consistent with the flight-testing accomplished during the Vista Sabre II and VCATS tests and the studies conducted by the Air Force Research Lab.

The only inconsistency was when transmissivity was reduced from a baseline of 25%. Reducing from 25% to 12% resulted in no significant reduction in target detection range. This could be due to an insufficient sample size or the possibility that a transmissivity cutoff point exists, beyond which a continued decrease in transmissivity does not have a significant impact on target detection range.

Visor Reflectivity

The data analysis conducted during this experiment did not support the research hypothesis that an increase in visor reflectivity would cause a reduction in target detection range. The following hypothesis could not be rejected: There is no difference in the visual target detection ranges among the same USAF F-15C, F-15E and F-16C pilots wearing a VCATS 25% uncoated visor, a VCATS 25% coated visor, and a JHMCS visor. Increasing reflectivity from a baseline visor with no reflective coating (4% inherent reflectivity) to visors with 9% and 13% reflective coatings had no affect on target detection range.

These results are inconsistent with prior flight-testing and AFRL research. The most likely cause of the inconsistency is the difference in lighting conditions between this experiment and prior testing. Specifically this experiment was conducted under very tightly controlled, static lighting conditions while the previous testing was conducted under more dynamic environmental conditions. The static conditions minimized both the number of unwanted reflections and the level of distraction caused by these reflections.

CHAPTER VII

RECOMMENDATIONS

The scope of this experiment was limited to ground testing with a very tightly controlled set of environmental lighting conditions. Specifically the experiment was conducted under static lighting conditions at midday on bright sunny days. Further testing should be accomplished to investigate different sun angles and to accommodate more dynamic lighting conditions such as changing sun position and direction during the data runs. Additional testing should also be accomplished to investigate the affect of transmissivity and reflectivity under less than optimum lighting conditions such as dusk, dawn, and under an overcast cloud layer.

An unanswered question generated during this experiment is whether or not a transmissivity cutoff exists. Further testing should also be accomplished to determine if reducing the visor transmissivity below 25% would continue to generate a significant decrease in target detection range.

Based on the transmissivity results found in this experiment, visor designers and pilots should pay particular attention to the light transmission properties of any transparent surface that is placed between the pilot's eyes and the target of interest. Although this experiment focused on visors, the same principles apply to all transparent surfaces on the aircraft such as the windscreen, canopy, and heads-up-display.

REFERENCES

Adam, E. C. (1995). Head-Up Displays Versus Helmet-Mounted Displays. St. Louis, MO: McDonnell Douglas Aerospace.

Esbach, O. W. & Souders, M. (1975). Handbook of Engineering Fundamentals. New York: John Wiley & Sons.

Gunther, M. (1995). Advanced Helmet Integrated Display Systems. San Jose, CA: Kaiser Electronics.

Jackson, P. R. (1998, January). Software Users Manual for Visually Coupled Acquisition and Targeting System. St. Louis, MO: The Boeing Company.

Kocian, D. F. (1995, November). Executive Summary Coordinated AL/CFH 6.2/6.3A Efforts for High Off-Boresight Angle (HOBA) Missile Cueing Systems. Wright Patterson AFB, OH: AL Crew Systems Directorate, Human Engineering Division.

Kocian, D. F. (1999, March). Technology vs. Reality: Finding What Works - Vista Sabre II/VCATS OUE. Briefing presented to the 422 Test and Evaluation Squadron, Nellis AFB, NV.

Kocian, D.F. & Task, H.L. (2000, February). Measurement of Military Helmet and Head-Mounted Display (HMD) Visor Optical Properties. Wright Patterson AFB, OH: Air Force Research Laboratory.

Lindberg, J. (1997). Fighter Tactics Academy [On-Line]. Available: http://www.sci.fi/~fta/missiles.htm

Marsh, J. S., Cushman, W. B. & Temme, L. A. (1991, November). Toward the Ideal Military Aviation Sunglass. Pensacola Naval Air Station, FL: Naval Aerospace Medical Research Laboratory.

McComas, J. M. (1998). A Study to Determine the Improvement of the F-15 VCATS Helmet Over That of Vista Sabre. Graduate Research Project presented to Embry-Riddle Aeronautical University, Nellis AFB, NV.

McDonnell Douglas Aerospace. (1997). T.O. 1F-15A-34-1-3 Nonnuclear Weapon Delivery Manual (Air-to-Air) USAF Series F-15A/B/C/D MSIP with VHSIC Aircraft. St. Louis, MO: Author.

Morris, A., Temme, L. A. & Hamilton, P. V. (1991, August). Visual Acuity of the U.S. Navy Jet Pilot and the Use of the Helmet Sun Visor. Aviation Space Environmental Medicine, 715-721.

Olson, W. B. (1996a). Helmet-Mounted Tracker and Display Interface with High Off-Boresight Angle Seekers – VISTA SABRE II, Special Project, Final Report. Nellis AFB, NV: United States Air Force Air Warfare Center.

Olson, W. B. (1996b). Visually-Coupled Acquisition and Targeting System (VCATS) Interface with High Off-Boresight Angle Seekers (HOBS) – VISTA SABRE II, Special Project, Test Plan. Nellis AFB, NV: United States Air Force Air Warfare Center.

Ryer, A. (1997, September). Light Measurement Handbook [On-Line]. Available: http://www.intl-light.com/handbook

Task, H. L. & Genco, L. V. (1985, February). The Measurement of Aircraft Windscreen Haze and Its Effect on Visual Performance. Wright Patterson AFB, OH: Air Force Aerospace Medical Research Laboratory.

Tinsley, T. (1994). Helmet Mounted Cueing Systems: Future Eyes in the Cockpit. Graduate Research Paper presented to Embry-Riddle Aeronautical University, Nellis AFB, NV.

APPENDIX A

BIBLIOGRAPHY

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American Psychological Association. (1994). Publication manual of the American Psychological Association (4th ed.). Washington, DC: APA.

Bender, A. R., Shultz, J. T., & Landgren, E. W. (1997). Guide to the graduate research project. (4th ed.). Daytona Beach, FL: Embry-Riddle Aeronautical University, Extended Campus.

Gay, L. R. (1996). Educational research: Competencies for analysis and application (5th ed.). Upper Saddle River, NJ: Prentice-Hall.

APPENDIX B

ACRONYMS

ACRONYMS

ACC	Air Combat Command
AFB	Air Force Base
AFRL	Air Force Research Laboratory
AL	Armstrong Laboratory
CRT	Cathode Ray Tube
FCR	Fire Control Radar
HMS	Helmet Mounted Sight
HMD	Helmet Mounted Display
HMT/D	Helmet Mounted Tracker and Display
HOBA	High off-boresight angle
HUD	Heads Up Display
JHMCS	Joint Helmet Mounted Cueing System
TES	Test and Evaluation Squadron
USAF	United States Air Force
USN	United States Navy
VCATS	Visually Coupled Acquisition and Targeting System
VTAS	Visual Target Acquisition System
WVR	Within-visual-range

APPENDIX C

DATA COLLECTION SHEET

DATA COLLECTION SHEET

Pilot #: ________________ Date: ______________ Start: _______ End: _____

Sky Conditions: __________________________

No Visor		**USAF Tinted**		**VCATS 25% Coated**		**VCATS 25% Uncoated**		**VCATS 35%**		**JHMCS**	
Seq		**Seq**		**Seq**		**Seq**		**Seq**		**Seq**	
Run 1											
Aspect											
Dist											
Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd	
Target		Target		Target		Target		Target		Target	
Barium		Barium		Barium		Barium		Barium		Barium	
Run 2											
Aspect											
Dist											
Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd	
Target		Target		Target		Target		Target		Target	
Barium		Barium		Barium		Barium		Barium		Barium	
Run 3											
Aspect											
Dist											
Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd	
Target		Target		Target		Target		Target		Target	
Barium		Barium		Barium		Barium		Barium		Barium	
Run 4											
Aspect											
Dist											
Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd	
Target		Target		Target		Target		Target		Target	
Barium		Barium		Barium		Barium		Barium		Barium	
Run 5											
Aspect											
Dist											
Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd		Bkgnd	
Target		Target		Target		Target		Target		Target	
Barium		Barium		Barium		Barium		Barium		Barium	

APPENDIX D

INDIVIDUAL PILOT TEST RESULTS

Table 14

Pilot 1 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	81	55	77	81	97	63
2	83	75	79	79	72	58
3	89	64	64	80	85	53
4	80	65	54	71	75	72
5	87	58	61	69	72	53
Avg	84	63.4	67	76	80.2	59.4
Lighting	**(millilux)**					
Background	488	486	485	487	439	432
Target	446	414	411	440	395	373
Barium	925	979	943	959	868	846

Table 15

Pilot 2 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	95	92	88	92	75	80
2	93	75	97	73	102	72
3	93	94	83	70	99	90
4	97	96	86	77	95	93
5	103	84	67	95	90	95
Avg	96.2	88.2	84.2	81.4	92.2	86
Lighting						
Background	497	479	485	491	484	486
Target	450	429	443	416	407	431
Barium	937	907	913	960	917	914

Table 16

Pilot 3 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	95	55	66	60	71	57
2	74	58	64	55	67	63
3	90	67	56	75	68	64
4	100	52	53	59	70	60
5	92	51	58	68	62	62
Avg	90.2	56.6	59.4	63.4	67.6	61.2
Lighting						
Background	489	468	443	481	473	501
Target	416	422	409	431	425	440
Barium	966	948	928	971	963	982

Table 17

Pilot 4 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	84	70	66	68	80	71
2	81	73	62	70	78	63
3	85	53	73	71	94	72
4	79	75	70	73	85	85
5	75	75	75	65	72	63
Avg	80.8	69.2	69.2	69.4	81.8	70.8
Lighting						
Background	454	463	452	458	462	455
Target	383	378	383	385	400	389
Barium	849	823	875	878	876	860

Table 18

Pilot 5 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	95	55	66	60	71	57
2	74	58	64	55	67	63
3	90	67	56	75	57	64
4	100	52	53	59	60	60
5	92	51	58	68	62	62
Avg	90.2	56.6	59.4	63.4	63.4	61.2
Lighting						
Background	488	491	463	468	457	482
Target	409	415	412	418	398	414
Barium	926	948	935	901	899	932

Table 19

Pilot 6 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	92	91	85	82	87	54
2	99	101	65	65	63	71
3	89	79	72	82	68	61
4	97	94	48	62	81	65
5	91	73	53	67	82	66
Avg	93.6	87.6	64.6	71.6	76.2	63.4
Lighting						
Background	479	485	497	487	481	480
Target	420	447	454	453	44	435
Barium	936	922	929	922	896	925

Table 20

Pilot 7 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	85	87	65	100	87	101
2	82	88	70	64	90	86
3	76	96	77	96	96	98
4	89	87	80	87	97	102
5	94	93	80	88	90	87
Avg	85.2	90.2	74.4	87	92	94.8
Lighting						
Background	509	503	502	506	512	512
Target	407	415	403	408	419	412
Barium	905	904	908	910	927	930

Table 21

Pilot 8 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	79	88	92	78	94	80
2	78	90	86	79	86	82
3	85	89	92	83	94	87
4	81	77	80	83	93	87
5	83	88	92	84	85	85
Avg	81.2	86.4	88.4	81.4	90.4	84.2
Lighting						
Background	493	482	486	491	497	498
Target	380	393	386	392	398	402
Barium	900	870	876	892	920	902

Table 22

Pilot 9 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	100	53	93	81	75	76
2	105	64	83	70	76	88
3	100	62	85	67	74	94
4	99	80	97	77	70	85
5	98	79	94	94	75	87
Avg	100.4	67.6	90.4	77.8	74	86
Lighting						
Background	692	561	694	494	512	653
Target	531	447	568	411	421	483
Barium	1033	930	1016	883	953	929

Table 23

Pilot 10 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	98	70	94	90	107	56
2	80	74	98	102	77	83
3	88	83	78	98	101	70
4	65	92	94	99	105	78
5	86	74	83	91	74	81
Avg	83.4	78.6	89.4	96	92.8	73.6
Lighting						
Background	501	500	494	511	504	518
Target	425	404	427	403	423	426
Barium	933	920	932	948	940	928

Table 24

Pilot 11 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	84	66	69	62	65	63
2	78	65	67	63	69	69
3	85	62	57	64	65	54
4	80	54	56	65	71	58
5	78	59	57	65	67	63
Avg	81	61.2	61.2	63.8	67.4	61.4
Lighting						
Background	492	505	504	516	521	504
Target	440	473	428	439	426	445
Barium	918	924	927	931	937	910

Table 25

Pilot 12 Test Results

Run	No Visor	USAF Tinted	VCATS 25% Coated	VCATS 25% Uncoated	VCATS 35%	JHMCS
1	81	58	60	52	65	57
2	70	65	52	55	63	53
3	83	57	52	60	68	55
4	79	61	53	58	60	49
5	73	60	56	50	60	52
Avg	77.2	60.2	54.6	55	63.2	53.2
Lighting						
Background	499	483	494	492	489	502
Target	398	420	405	384	431	386
Barium	928	901	945	917	898	919

APPENDIX E

T-TEST RESULTS

Table 26

No Visor / USAF Tinted Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	-177.6
Mean of D's	-15.0
Sum of "D^2"	4748.80
t-Value	-3.75
Degrees of Freedom	11

Table 27

No Visor / VCATS 25% Coated Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	-181.20
Mean of D's	-15.00
Sum of "D^2"	4513.12
t-Value	-3.75
Degrees of Freedom	11

Table 28

No Visor / VCATS 25% Uncoated Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	-157.20
Mean of D's	-13.00
Sum of "D^2"	3794.96
t-Value	-3.25
Degrees of Freedom	11

Table 29

No Visor / VCATS 35% Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	-102.20
Mean of D's	-9.00
Sum of "D^2"	2860.36
t-Value	-2.25
Degrees of Freedom	11

Table 30

No Visor / JHMCS Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	-187.8
Mean of D's	-16.00
Sum of "D^2"	4748.44
t-Value	-4.00
Degrees of Freedom	11

Table 31

USAF Tinted Visor / VCATS 25% Coated Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	-3.6
Mean of D's	0.0
Sum of "D^2"	1495.12
t-Value	0.0
Degrees of Freedom	11

Table 32

USAF Tinted Visor / VCATS 25% Uncoated Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	20.40
Mean of D's	2.00
Sum of "D^2"	1029.36
t-Value	0.67
Degrees of Freedom	11

Table 33

USAF Tinted Visor / VCATS 35% Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	75.40
Mean of D's	6.00
Sum of "D^2"	1063.48
t-Value	3.00
Degrees of Freedom	11

Table 34

USAF Tinted Visor / JHMCS Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	-10.2
Mean of D's	-1.0
Sum of "D^2"	1086.92
t-Value	-0.33
Degrees of Freedom	11

Table 35

VCATS 25% Coated Visor / VCATS 25% Uncoated Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	24.00
Mean of D's	2.00
Sum of "D^2"	586.88
t-Value	1.00
Degrees of Freedom	11

Table 36

VCATS 25% Coated Visor / VCATS 35% Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	79.00
Mean of D's	7.00
Sum of "D^2"	1321.48
t-Value	3.50
Degrees of Freedom	11

Table 37

VCATS 25% Coated Visor / JHMCS Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	-6.60
Mean of D's	-1.00
Sum of "D^2"	770.36
t-Value	-0.50
Degrees of Freedom	11

Table 38

VCATS 25% Uncoated Visor / VCATS 35% Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	55.00
Mean of D's	5.00
Sum of "D^2"	537.72
t-Value	5.00
Degrees of Freedom	11

Table 39

VCATS 25% Uncoated Visor / JHMCS Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	-30.60
Mean of D's	-3.00
Sum of "D^2"	1009.16
t-Value	-1.00
Degrees of Freedom	11

Table 40

VCATS 35% Visor / JHMCS Visor T-Test Results

Statistic	Value
No. of Pairs of Scores	12
Sum of "D"	-85.60
Mean of D's	-7.00
Sum of "D^2"	1480.16
t-Value	-2.33
Degrees of Freedom	11